U Geminorum: a test case for orbital parameters determination

Juan Echevarría, Eduardo de la Fuente Acosta & Rafael Costero

Instituto de Astronomía, Universidad Nacional Autónoma de México

We present a new method to obtain the radial velocity semi-amplitude of the secondary star: K_2, based on a co-phasing method to detect absorption features like, for example, FeI or CaI lines, TiO or CN bands, as well as from hot spots in its surface like Hα in emission. Results from Echelle spectroscopy are presented and compared with published results. We also present new measurements of the wings of the Hα emission which agrees with the ultraviolet results. From a comparison of the 7050 Å TiO band, detected for the first time with the co-phasing method, we find a best fit for an M6 star, contributing five percent only of the total light in that spectral region. Assuming that the radial velocity semi-amplitudes reflect accurately the motion of the binary components, we obtain: $K_{em} = K_1$=108 km s^{-1} and $K_{abs} = K_2$ = 310 km s^{-1}.

Introduction

Due to its eclipsing nature and thorough observational studies, U Gem is, in general, a good candidate for the analysis of standard and new methods in the determination of the orbital parameters in cataclysmic variables. Although in this interactive binary, these parameters are relatively well known, there are still discrepancies in the radial velocity semi-amplitude of the white dwarf, as obtained from the optical or the Ultraviolet data.

Furthermore, the secondary star is not visible in the optical; consequently, its corresponding semi-amplitude has been derived from data obtained in the infrared region. For these reasons U Gem is an interesting case for testing new methods to derive orbital parameters based on optical observations only. Thirty-one high resolution spectra of U Gem, covering the spectral region λ5200-9100 Å, were obtained. The system was observed in January 1999 during quiescence, about 35 days after the onset of an outburst.

Orbital and Physical Parameters of U Gem

i	70 ± 2	(a)
γ (km s^{-1})	43 ± 6	(b)
K_1 (km s^{-1})	108 ± 2	(c)
K_2 (km s^{-1})	310 ± 5	(c)
HJD_0 (240000+)	37638.82325	(d)
P_{orb}	0.1769061911	(d)

M_{wd}	1.20 ± 0.05 $M_\odot$	(c)
M_{rd}	0.42 ± 0.04 $M_\odot$	(c)
a	1.5 ± 0.02 $R_\odot$	(c)

References

(a) Zhang et al., 1987, ApJ, 321, 813;

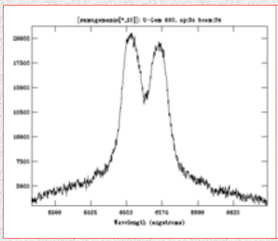
(b) Friend et al., 1991, MNRAS, 246, 637;

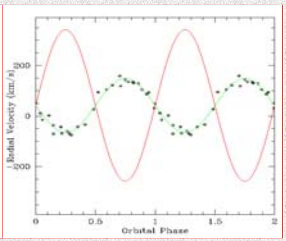
(c) This Paper;

(d) Marsh et al., 1988, MNRAS, 235, 269

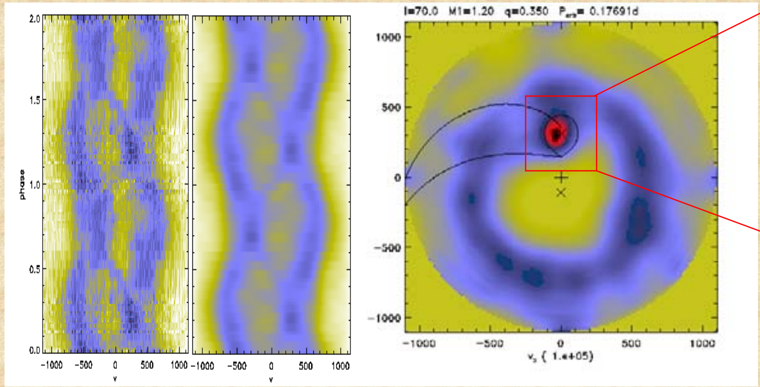
To determine K_{abs} for an object, for which the orbital period and the time for the inferior conjunction are known, we reverse the process: derive a *V(t)* from the HJD of the individual spectra assuming an initial value of K_{abs} and using the known P_{orb} and HJD_o The individual spectra are then **co-added** in the frame of reference of the secondary star, i.e. we Doppler-shift the spectra using the calculated *V(t)* and then add them together. We call this process ***co-phasing***. As we vary K_{abs} along a range of possible values, there will be one for which the *co-phased* absorption or emission features of the associated with the secondary star will reach an optimal maximum or line depth. There are several absorption lines, like ions of FeI and CaI, molecular bands like TiO or CN, and even emission lines which may be possible to use with this method. We show two examples for the case of U Gem. The first is the *co-phasing* of the Hα hot-spot and the second is the co-phased spectrum of the NaI doublet *λλ8183,8195* Å. We were able also to detect the TiO band at *λ7050* Å, but, due to the poor signal to noise ratio of the data were not able to produce a Head-strength vs. K_{abs} plot. This co-addded spectrum is shown at the far right and is compared with an M6 star contributing 90 percent of the total light.

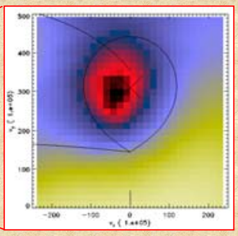
Radial Velocity Results for the Accretion Disk





An example of the Echelle Ha spectra (left) with peak separation of 890 km s^{-1} . The wings of the emission lines were measured using the standard double Gaussian technique and diagnostic diagrams as described in Shafter, et al., 1986, ApJ, 308, 765. The individual Gaussians have a fixed width of 26 Å. The double-Gaussian program was run for a separation range from about 60 to 120 Å. The radial velocities for U Gem (right) correspond to the measurements of the wings. The best solution is for K_1 = 108 km s^{-1} in agreement with the ultraviolet results of Long & Gilliland, 1999, ApJ, 511, 916. The solid line close to the points correspond to the solution shown in the Table. The large amplitude line correspond to the solution found for K_2 = 310 km s-1 K_2 with the co-phasing method.

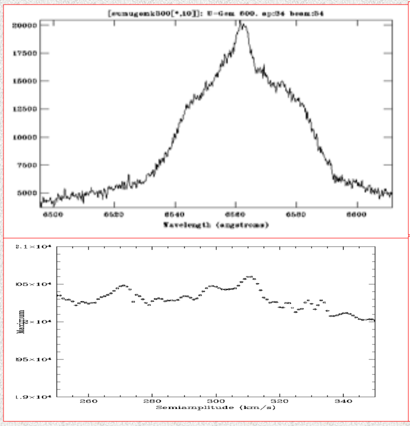




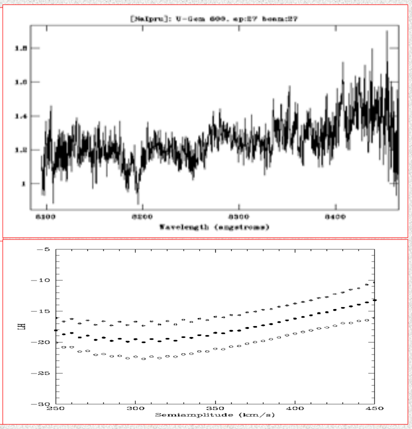
Doppler Tomography Results

Based on the separation of the Hα double emission peaks, we calculate an outer disk radius of R_{out}/a ~ 0.63, similar to the distance of the inner Lagrange point L_1/a ~ 0.63. Therefore we suggest that, at the time of observations, the accretion disk was filling the Roche-Lobe of the primary, and that the matter leaving the L_1 point was striking the disc directly, producing the hot spot near the L_1 location. The V_y velocity of the spot in the Doppler Tomography is consistent with that determined from the co-phasing method.

Method to determine K_2

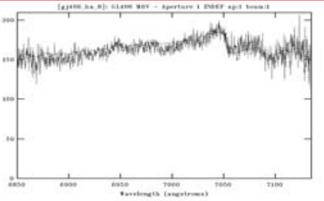


Hα co-added spectrum in the secondary star frame (top) and maximum flux as a function of K_{abs} (bottom).



Co-phased spectrum of the Na I doublet (top) andmaximum flux depth of the individual NaI lines 8183.3 Å (up), 8194.8 Å (down) and mean (middle) as function of K_{abs}

The Spectral Type of the Secondary Star



TiO head band spectra compared with an M6 star spectra (dotted line) contributing 95 percent of the flux at this wavelength interval.